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FINAL TECHNICAL REPORT

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Final Report

"Dynamics Explorer Data Analysis"

NASA Grant NAG 5-775

May 16, 1986 - June 30, 1993

(including last semiannual report covering November 16, 1992 - June 30, 1993)

I. Accomplishments

Over the course of the past decade, we have made many accomplishments in our understanding of the aurora, magnetosphere, and ionosphere as a result of the Dynamics Explorer mission. Much of the work was directly funded by this grant NAG 5-775 and its predecessor NAG 5-302; some of the research was funded by other grants and facilitated by the access to the Dynamics Explorer plasma and convection data sets afforded by this grant. Two Ph.D.'s (Rudy Frahm and Gang Lu) were awarded as a result of this grant, and five other graduate students were partially supported. In addition, three Senior Theses and four postdoctoral students were supported. The ending of our funding did not mean the end of our efforts - we have found others sources of support to continue this important and exciting work, and research at some level of effort is continuing.

Plasma Physics of the Auroral Acceleration Region

Our work on auroral acceleration processes over the years has built on the unique ability of Dynamics Explorer to observe plasmas both above and below the acceleration region, nearly simultaneously. We able to show that pioneering models based on rocket and S3-3 data were correct, that is, the principal auroral acceleration mechanism is a field-aligned electric field, accelerating electrons downward and simultaneously accelerating ions upward [*Reiff et al.*, 1986]; [*Reiff et al.*, 1988]. Hydrogen and Oxygen were given the same energy per charge, not the same velocity, pointing to an electric field source for the energization. Heating of the upgoing ions and downcoming electrons is a secondary effect, not a primary one. Studies of heating of the upflowing ions by the two-stream instability were funded by this grant [*Bergmann et al.*, 1988]; [*Roth et al.*, 1989], and have continued since. We showed that the current structures appear to map between high and low altitudes [*Reiff et al.*, 1989].

We have studied the current carriers for dayside auroral currents [*Burch et al.*, 1983] and studied the auroral current-voltage relationship [*Lu et al.*, 1991]; [*Marshall et al.*, 1991], confirming the Knight current-voltage formula in general. Most recently, we studied the low altitude limit of the auroral acceleration region by matching upgoing ion fluxes at high and low altitude [*Lu et al.,* 1992], yielding a value of about 1200- 1500 km for an effective loss height. The high altitude limit of the auroral acceleration region was studied by statistical means, yielding an effective upper limit to the auroral acceleration region of 14,000 km, with the only exceptions being substorm surges [*Reiff et al.,* 1993]. We studied a major magnetic storm and its effects on earth's "space weather" [*Allen et al.,* 1989] . We have investigator statistical models of particle precipitation into the thermosphere [*Reiff,* 1985] and helped provide data for global models of thermospheric motion [*Roble et al.*, 1988]

We have also studied the mapping of the auroral particles into the magnetotail, using various magnetic field models. We compared the densities and temperatures from the high altitude DE spacecraft with statistical models of plasma sheet ions and electrons, to test the validity of the model and to determine the range of distances for the CPS/BPS boundary [*Weiss et al.,* 1992a]. This study was updated for presentation at the IAGA meeting in 1993 (see presentation list below). Senior Nancy Chabot continued work on this project for her Senior Thesis (1994); this is being written up for publication. We have recently been funded by the NASA SR&T program to perform more mapping studies, including a study of electron loss rates by analyzing DE electron data.

Electrodynamic Coupling as a Function of Substorm Phase and IMF Direction

This grant has supported much work on the characteristics of ionospheric convection as a function of interplanetary parameters, as a followon to our work funded by the predecessor grant [*Burch et al.,* 1985]; [*Reiff and Burch,* 1985]. In those papers we put forth the idea of a 'lobe cell' which can be observed simultaneously with a 'viscous cell' and a 'merging cell'. Those ideas, controversial at the time, have since been confirmed by our own work and those of others. Grant-supported work in this area includes [*Reiff and Luhmann,* 1986]; [*Heelis et al.,* 1986]; [*Coley et al.,* 1987]; [*Lu et al.,* 1989]; [*Moses and Reiff,* 1991]; [*Nagai et al.,* 1993]. A recent paper used convection measurements to argue that the convection during Northward IMF was indeed a four-cell and not a distorted two-cell pattern, at least at times [*Reiff and Heelis,* 1994].

We presented an invited paper on convection during Northward IMF at the IAGA meeting in summer 1991 which is now in press [*Moses and Reiff,* 1994]. A recent paper used convection measurements to argue that the convection during Northward IMF was indeed a four-cell and not a distorted two-cell pattern, at least at times [*Reiff and Heelis,* 1994]. We presented an invited paper on substorm energy dissipation at the Kiruna substorm meeting in March 1992. In that paper we summarized knowledge of dissipation rates, giving empirical formulae when available [*Weiss et al.,* 1992b].

We also determined the dependence of the polar cap potential drop on IMF conditions, [*Reiff and Luhmann,* 1986]; and updated them using Dynamics Explorer convection data [*Reiff,* 1990; *Moses and Reiff,* 1991]. We also calculated the distribution of the convection potential around the polar cap as a function of IMF direction [*Lu et al.*, 1989]. We are presently working on updating these two studies using DMSP data, funded separately [*Ben Boyle*, thesis in progress, 1994].

Particle Injection in the Magnetospheric Cusp

We have long been active in studying the injection of magnetosheath plasma into the cusp [*Reiff et al.*, 1977]; [*Hill and Reiff*, 1977]; [*Reiff et al.*, 1980]. With the advent of Dynamics Explorer, we extended this study to the pitch-angle-dependent ion dispersion signature [*Burch et al.*, 1982]. More recent work by the Viking plasma detector has also confirmed this dispersion signature. We discovered a similar convective dispersion related to upgoing ions from auroral arcs [*Frahm et al.*, 1986]. We recently reviewed cusp ion dispersion signatures for the NATO cusp meeting (see presentation list below). We have used the ion dispersion to infer the location of the dayside Xline [*Lu et al.*, 1994]. As a followon (funded separately), we are working with Terry Onsager to use his model to recreate ion dispersion signatures from DE using the Toffoletto-Hill electric field model.

II. Summary of Accomplishments

* Have shown that auroral arcs are *only* explainable by parallel electric fields.
* Comparing AE (solar minimum) versus DE (solar maximum) data shows that the functional form of the dependence of the polar cap potential drop on the IMF does not strongly depend on solar cycle (therefore not on polar cap conductivity).
* We have identified a time when the DE-1 spacecraft was in the high altitude cusp when ISEE-1 was observing an FTE signature near the equatorial plane, at approximately the same magnetic local time. The ions show a typical merging dispersion signature. DE-2, nearly conjugate in the opposite hemisphere, showed a particle signature which is consistent with steady-state merging but not with impulsive injection (the highest energy particles were observed at the lowest latitudes but not at the earliest time, since the spacecraft was traveling equatorwards). Thus apparently FTEs can coexist with steady-state merging.
* We calculate an empirical auroral parallel conductance of $0.5\text{-}2 \times 10^{-9}$ mho/m from DE1/2 conjunction data.
* The high-altitude limit of significant downward auroral electron acceleration is about 14,000 km, with less than 20% of the passes at that altitude showing downward acceleration of 1 keV or more. This ratio increases to almost 100% at 9,000 km.
* We have investigated the effects on spacecraft and on the ground of a major auroral storm which occurred on March 13-14, 1989. Auroras were observed as far south as Brownsville, Texas, and power outages as far south as Los Alamos, New Mexico were experienced. Over six million people depending on the city of Quebec for their electric power were in the dark for

9 hours when a transient current induced in a transmission line tripped the breakers. The DE-1 spacecraft observed the largest auroral oval it ever recorded.

* The low-altitude limit of significant upward ionospheric ion acceleration is about 1200 - 1500 km. Times with higher potential drop correspond to lower acceleration altitudes, and vice versa.

III. Publications Supported or Facilitated

Papers Since the Last Reporting Period

Weiss, L. A., P. H. Reiff, R. Hilmer, J. D. Winningham, and G. Lu, "Mapping the Aurora into the Magnetotail Using Dynamics Explorer Plasma Data", *J. Geodes. Geomagn.*, **44**, p. 1121-1144, (1992).

Reiff, P. H., G. Lu, J. L. Burch, J. D. Winningham, L. A. Frank, J. D. Craven, W. K. Peterson, and R. A. Heelis, "On the high- and low-altitude limits of the auroral electric field region", in **Auroral Plasma Dynamics**, *Geophys. Monogr. Ser.*, Vol. 80, ed. R. Lysak, pp. 143-154, AGU, Washington, D. C. (1993).

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Bergmann, R., I. Roth and M. K. Hudson, Linear stability of the H+ - O+ two-stream interaction in a magnetized plasma, *J. Geophys. Res.*, **93**, 4005-4020, 1988.

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Heelis, R. A. and P. H. Reiff, "Observations of Magnetospheric Convection from Low Altitudes," *Adv. Space Res.*, ed. E. R. Schmerling, S. W. H. Cowley and P. H. Reiff, **5**, pp. 349-362, 1985.

Heelis, R. A., P. H. Reiff, J. D. Winningham and W. B. Hanson, Ionospheric convection signatures observed by DE 2 during northward interplanetary magnetic field, *J. Geophys. Res.*, **91**, 5817-5830, 1986.

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Weiss, L. A., P. H. Reiff, J. J. Moses, R. A. Heelis and B. D. Moore, Energy dissipation in substorms, in ***Substorms - 1**, Proceedings of the International Conference on Substorms (ICS-1), SP*, **335**, edited by pp. 309-317, ESA, Nordwijk, Netherlands, 1992b.

IV. Public Presentations (since last reporting period)

Reiff, P. H., “Mid-altitude Particle Signatures of the Cusp”, invited lecture, NATO Cusp Meeting, Oslo, Norway, May 10 (1993).

Reiff, P. H., “Auroral Particle Acceleration”, Prairie View Science Academy, Rice University, Houston, June 11 (1993).

Reiff, P. H., “Mapping the Aurora into the Magnetotail”, invited talk, IAGA, Buenos Aries, Argentina, August 12 (1993).

Reiff, P. H., “Tour of the Solar System”, talk for "Astronomy Day", held at Rice University, October 24 (1993).

Reiff, P. H., “Astronomy”, presentation to Gifted and Talented 3rd grade class, West University Elementary School, Houston, November 10 (1993).

Reiff, P. H., “Ionospheric Convection and the Aurora”, Colloquium, Auburn University, Auburn, Alabama, February 4 (1994).

V. Graduate Students Supported

Two Ph.D.'s have been granted directly supported by this grant:

Rudy A. Frahm (1987) (now at Southwest Research Institute)

Gang Lu (1991) (now at High Altitude Observatory, NCAR)

also, partial support for: Loretta Weiss (Ph.D. 1992); John Shade, B. Sen, Brian Moore, and C. Ben Boyle

Senior Theses: Reneé James (1991); David Alexander (1992); Nancy Chabot (1994)

Postdoctoral Students Supported: Rachelle Bergmann; Gang Lu; Loretta Weiss; Julie Moses